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Short Communication

Effect of biological soil crusts (BSCs) composition on early establishment of vascular plants in eroded soils

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Abstract

Biological soil crusts (BSCs), composed of lichens and bryophytes among the most conspicuous organisms, colonize and stabilize eroded soils, provide nutrients and interact with vascular plants. The effect of BSCs on germination and early establishment of plants is far from being fully understood. The relationship between BSC composition and vascular plants has been found to be species-specific. In this study, we evaluated how BSC composition affects germination and early establishment in two species of vascular plants (*Jarava juncoides* and *Noticastrum marginatum*) present in eroded areas of the Sierras Grandes de Córdoba, central Argentina. We conducted a laboratory experiment that consisted of sowing seeds of the two plant species on different types of BSC cover: *Diploschistes* spp. (crustose lichens), *Xanthoparmelia* spp. (foliose lichens), *Cladonia* spp. (fruticose lichens), *Polytrichum* sp. (bryophytes), and bare soil as control treatment. We recorded the number of germinated seeds and of established seedlings for two months. Bryophytes and lichens did not facilitate seed germination in the controlled environment; however, early establishment was not affected by the treatments. The interaction between BSCs and germination and early establishment of the studied vascular plants was found to depend on the dominant composition of the BSCs and the plant species.

Key words: cryptogams, *Jarava juncoides*, lichens, mosses, *Noticastrum marginatum*.

Resumen

Las costras biológicas, compuestas por líquenes y briófitos, entre los organismos más conspicuos, son pioneras en suelos erosionados, ayudan en su estabilización, proveen nutrientes e interactúan con las plantas vasculares. No obstante, el efecto de las costras biológicas sobre la germinación y el establecimiento temprano de las plantas vasculares está lejos de ser entendido complemente, y los resultados encontrados son especie-específicos respecto a la composición de la costra y las especies de plantas vasculares que intervienen en la relación. En este estudio, nos propusimos evaluar cómo afecta la composición de la costra biológica en la germinación y el establecimiento temprano de dos especies de plantas vasculares (*Noticastrum marginatum* y *Jarava juncoides*) presentes en áreas erosionadas de las Sierras Grandes de Córdoba, en el centro de Argentina. Para tal fin se ha realizado un experimento de laboratorio colocando semillas de las dos especies de plantas sobre distintos tipos de cobertura de suelo: cubierto por *Diploschistes* spp. (crustoso), *Xanthoparmelia* spp. (folioso), *Cladonia* spp. (fructiculoso), *Polytrichum* sp. (briófito) y un tratamiento control de suelo desnudo. Se ha evaluado el número de semillas germinadas y plántulas establecidas durante dos meses, y se ha encontrado que briófitos y líquenes no facilitan la germinación de semillas en un ambiente controlado. Sin embargo, el establecimiento temprano no se vio afectado por los tratamientos.. La interacción entre las costras biológicas del suelo y la germinación y establecimiento temprano de las plantas vasculares depende de la composición dominante de la costra y de las especies de plantas.

Palabras clave: criptógamas, *Jarava juncoides*, líquenes, musgos, *Noticastrum marginatum*.

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Lichens and bryophytes are the most conspicuous components of biological soil crusts (BSCs) (Eldridge & Greene 1994; Belnap 2003; Veste 2005); either group may be dominant, depending on the climatic conditions and microhabitat (Belnap 2003; Rivera-Aguilar *et al.* 2005; Pinzón & Linares 2006; Elbert *et al.* 2012; Navas-Romero *et al.* 2021). BSCs are distributed worldwide; however, most studies have been conducted in arid and semiarid areas, with temperate or tropical environments, like seasonal dry forests of South America, having received less attention (Belnap *et al.* 2001; Castillo-Monroy *et al.* 2016).

BSCs play an important role in germination, establishment and growth of vascular plants, since they modulate infiltration, nutrient content and soil moisture (Belnap 2003). Several studies have shown that the effect of BSCs on vascular plants can be positive, negative or neutral (Bowker 2007). On the one hand, some studies show a correlation of lichen-dominated soils with low densities of vascular plants. The possible explanations to this correlation are inhibition of seed germination by the extracts released from lichens tissues and/or a mechanical effect of the smooth surface of the BCSs, which prevents seeds from reaching the ground (Prasse & Bornkamm 2000; Sedia & Ehrenfeld 2003; Serpe *et al.* 2006; Langhans *et al.* 2009). By contrast, other works indicate positive effects on germination in soils dominated by BSCs (Lesica & Shelly 1992; Defalco *et al.* 2001; Boeken *et al.* 2004; Rivera-Aguilar *et al.* 2005). Recently, Zeberio & Peter (2021) reported that plant establishment depends on soil moisture content rather than on the presence of bryophyte-dominated BSCs. Further studies are necessary to understand plant responses to BSCs. Some studies help to understand the contradiction of the previous conclusions. For instance, Castillo-Monroy & Maestre (2011) reported species-specific results for the success of seed germination and seedling establishment, while other studies highlight the influence of BSC composition, since seedling emergence was found to be reduced in crustose lichen-dominated BSCs. The morphology of this type of lichens is likely to cover or “seal” the soil, reducing water availability for seed germination. Therefore, knowledge about the species involved in this relationship helps to better understand their interaction.

The landscape of the Sierras Grandes de Córdoba, Argentina, is a mosaic of forests, grasslands and rocky outcrops (Cingolani *et al.* 2004). The long history of livestock pressure in the area has resulted in eroded zones with variation in plant cover (Cingolani *et al.* 2008), with some of those zones showing different BSCs assemblages (Perazzo & Rodríguez 2019). A study conducted to identify the common vascular plant species present in eroded soils of the Sierras Grandes de Córdoba (Herrero 2019) indicated that *Noticastrum marginatum* (Kunth) Cuatrec., Webbia (family Rosaceae) and *Jarava juncoides* (Speg.) Peñail. (family Poaceae), both of perennial habits (Zuloaga & Belgrano 2015), were very abundant and frequent in eroded areas. In addition, plants showed high percentages of germination in the laboratory and high survival when planted in eroded soils. The relationship between vascular plants and BSCs components commonly found in the Sierras Grandes has been little explored; studying this interaction may provide tools to help guide decision making regarding restoration.

The aim of this study was to evaluate whether germination and early establishment of *J. juncoides* and *N. marginatum* are influenced by the dominant component of the BSCs. We performed a laboratory experiment consisting of the following treatments: bare soil, soil covered by bryophytes, and soil covered by crustose, foliose and fruticose lichens. We expected that both germination and establishment of vascular plants commonly occurring in eroded soils (*N. marginatum* and *J. juncoides*) would be influenced by the substrate available for germination, since the morphology of BSCs differs depending on the BSC component: lichen or moss. We hypothesize that germination and early seed establishment of vascular plant species would be greater in bare soil than in soil covered by BSCs, and in moss-dominated BSCs than in lichen-dominated BSCs. Samples of soil covered by biological crusts were taken from an area in the Sierras Grandes de Córdoba, Argentina, 31°36’05.4”S, 64°51’44.8”W, 7.VI.2017. The treatments were determined according to the dominant component of the BSCs at the site: bryophytic or any of the three lichen growth forms, crustose, foliose or fruticose (including dimorphic lichens). Treatments with BSCs were composed as follows: bryophytes (*Polytrichum* sp.); crustose lichens (*Diploschistes* spp., mainly *D. conceptionis* and *D. scruposus*); foliose lichens (*Xanthoparmelia* spp. mainly *X. taractica* and *X. santesonii*); and fruticose lichens *Cladonia spp.* (mainly *C. fimbriata*, *C. pixidata* and *C. melanopoda*). Samples were placed on plastic trays (12 × 15 × 4 cm), with 15 trays being used for each treatment. The control treatment consisted of 15 trays containing bare soil obtained from the same collection site. Seeds (n = 10) of each of the vascular plant species, *N. marginatum* and *J. juncoides*, were placed on the surface on these substrates.

The trays were placed in a germination chamber under standardized environmental conditions: 25/15 °C and 12/12 h (light/darkness) photoperiod (Funes *et al.* 1999) and regularly irrigated with distilled water to control moisture (Funes *et al.* 2009). Germination and early establishment were recorded every three days during two months. The criterion for germination was radicle emergence (2 mm); the results are expressed as percentage of germinated seeds (ISTA 2011). The criterion for determining early establishment was the presence of true leaves during the first two months after germination, a period considered sufficient to evaluate establishment of these species (García & Villamil 2001). Each individual was identified visually and species were identified with a pin of different color, which allowed us to measure survival. In parallel, the seeds collected in the field were subjected to a germination test in the laboratory to check their viability (Garcia & Villamil 2001). For this, 10 seeds of each vascular plant species were placed in a previously sterilized petri dish lined with filter paper moistened with distilled water. For each species, 10 repetitions were incubated in a germination chamber together with the tray samples and under the same environmental conditions. The results of this procedure showed a total percentage of germinated seeds of 83% for *N. marginatum* and 88% for *J. juncoides.*

A generalized linear model (GLM) using binomial distribution with one variable and five levels was performed to evaluate if seed germination and seedling establishment of vascular plants varied among treatments. Data on germination and seedling establishment were used as response variables. The DGC posthoc test was used. The analysis was performed using the software INFOSTAT and its interface with R.

Germination of *N. marginatum* seeds differed significantly among treatments (F value = 22.87; p < 0.0001). Germination was highest in the control treatment, with significant differences from the *Polytrichum* sp., *Cladonia* spp. and *Xanthoparmelia* spp. treatments. The lowest germination values were recorded in the *Diploschistes* spp. treatment, with significant differences from the remaining treatments. Germination percentages were 71% in the control treatment, and 55% in *Polytrichum* sp., 57% in *Xanthoparmelia* spp., 45% in *Cladonia spp*., and 13% in *Diploschistes* spp. treatments (Fig. 1a).

Germination of *J. juncoides* showed significant differences among treatments (F value = 12.76; p < 0.0001), being significantly higher in the control treatment than in the *Polytrichum* sp. treatment. Germination in the lichen treatments was significantly lower than in the control and in the *Polytrichum* sp. treatment. Germination percentages were 91% for the control, 73% for *Polytrichum* sp., 67% for *Xanthoparmelia* spp., 56% for *Cladonia* spp. and 55% for *Diploschistes* spp. (Fig. 1b).

Seedling establishment did not differ among treatments for either vascular plant species. Seedling establishment of *N. marginatum* was 95% in the control treatment, 100% in *Polytrichum* sp., 90% in *Xanthoparmelia* spp., 93% in *Cladonia* spp. and 66% in *Diploschistes* spp. (F value = 1.44; p = 0.2299, Fig. 2a). Seedling establishment of *J. juncoides* was 100% in the control treatment, 100% in *Polytrichum* sp., 92% in *Xanthoparmelia* spp., 97% in *Cladonia* spp. and 95% in *Diploschistes* spp. (F value = 0.11; p = 0.9781, Fig. 2b).

The effect of BSCs on the germination of *N. marginatum* and *J. juncoides* was negative with respect to that of bare soil. These results agree with

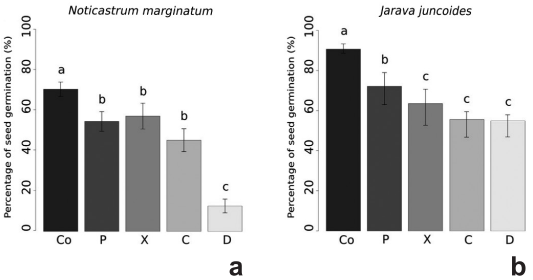

Figure 1 – a-b. Percentage of seed germination – a. *Noticastrum marginatum*; b. *Jarava juncoides*. Different lower case letters indicate significant differences among treatments (posthoc DGC test). Bars represent the standard error. Abbreviations: Co = control; P = *Polytrichum* sp. (bryophyte); X = *Xanthoparmelia* spp. (foliose lichen); C = *Cladonia* spp. (fructicose lichen); D = *Diploschistes* spp. (crustose lichen).

previous works addressing the relationship between biological crusts and germination of vascular plants (Eldridge *et al.* 2000; Prasse & Bornkamm 2000; Sedia & Ehrenfeld 2003). The comparison among treatments for each species separately shows that germination of *N. marginatum* seeds was lower than that of *J. juncoides.* It has been proposed that germination on BSCs would depend on seed traits, such as size (Li *et al.* 2008; Funk *et al.* 2014), since the smaller the seed, the more likely to penetrate the layer formed by the BSCs and reach the soil (Funk *et al.* 2014). Seed size, shape and presence of appendage (Briggs & Morgan 2011) were more favorable for *J. juncoides* in terms of the possibility of reaching the substrate through the lichen thalli and the leaves of bryophytes. Indeed, the seed of that species is elongated and thin, with a long and flexible anthecium side; anthecium is arrow-shaped, which not only favors dispersal through ectozoochory (Claure-Herrera *et al.* 2020) but also helps to better penetrate the substrate. The large seeds of *N. marginatum* would be less likely to penetrate the cryptogam layer.

Treatments with *Diploschistes* spp. exhibited the lowest seed germination for both species. The thallus of this crustose lichen forms a very compact cover that attaches to the substrate, leaving little space available for seeds to reach the soil. Tavili *et al.* (2017) indicated that moisture is one of the main factors affecting seed germination, and that the soil moisture condition is affected by cryptogam cover. Germination of *N. marginatum* in crustose lichens was significantly lower than in the remaining treatments; this result may be attributed to the lichen structure mentioned above. However, no significant differences were found among crustose, foliose and fructose lichen treatments for *J. juncoides*. The seeds of these species may be able to germinate in the spaces between thalli of *Diploschistes* sp. as well as between the squamules of *Cladonia* spp. or the lobules of *Xanthoparmelia* spp.

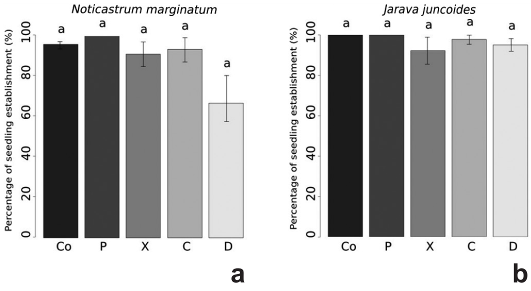

Figure 2 – a-b. Percentage of seedling establishment per treatment – a. *Noticastrum marginatum*; b. *Jarava juncoides*. Different lower case letters indicate significant differences among treatments (posthoc DGC test). Bars represent standard error. Abbreviations: Co = control; X = *Xanthoparmelia* spp. (foliose lichen); P = *Polytrichum* sp. (bryophyte); C = *Cladonia* spp. (fructiculose lichen); D = *Diploschistes* spp. (crustose lichen).

Treatments with the bryophyte showed intermediate values, with significant differences, between control and *Diploschistes* spp. for *N. marginatum* and between control and the lichen treatments for *J. juncoides*. Bryophytes retain water and release it slowly to the environment, providing moisture for seeds (Calabrese & Rovere 2013). Moreover, when seedling roots of vascular plants have reached the soil, their seeds can use soil water that is not available to bryophytes (Jeschke & Kiehl 2008). The cover of bryophytes provides vascular plants with a humid microclimate with reduced thermal amplitude (Turetsky 2003; Czarnecka 2004). However, bryophytes may negatively affect seed germination by blocking access to light (Zamfir 2000; Jeschke & Kiehl 2008), since a dense bryophyte cover reduces red/far red ratio of the transmitted light. Seeds can detect this proportion through Phytochrome B and, therefore, do not germinate under low values (Jeschke & Kiehl 2008). This process might explain the germination pattern found in the bryophyte treatment with respect to the other treatments.

BSCs did not have a significant effect on early seedling establishment, except for *N. marginatum* under *Diploschistes* spp., which had a slightly lower seedling establishment percentage than germination percentage. Therefore, BSCs would not act as a barrier to seedling establishment after germination.

Germination percentage of both species was higher in the control than in the BSC treatments. However, in the field, the gradual loss of bare soil due to water and wind erosion (Cingolani *et al.* 2013) hinders seed retention. Therefore, BSCs would be playing the role of seed retention, while also providing lower temperature and higher humidity conditions than bare soil (Verrecchia *et al.* 1995). In addition, our results show that germination percentage values in treatments with cryptogamic cover are also high (most of them are close to 50%, except for *N. marginatum* in the *Diploschistes* spp. treatment); therefore, succession in the natural environment may be favored by the presence of BSCs in eroded soils.

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Data availability statement

In accordance with Open Science communication practices, the authors inform that all data are available in <http://hdl.handle.net/11336/231186>.

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